Atmospheric Correction of Vegetation index Using Multi-angle Measurements

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Abstract -- The Vegetation Index can be derived from top-of-atmosphere red and near-infrared radiances assuming no prior knowledge of atmospheric properties, when the observations are made at a number of different view zenith angles. The analysis is a fast, simple regression procedure involving only the radiance measurements and no radiative transfer modelling. The technique is insensitive to aerosol optical properties such as optical depth and phase function shape. Instruments which routinely make multi-angle observations (e.g., the airborne ASAS and EOS-AM1 spacecraft MISR) can benefit from the use of Uris technique.

INTRODUCTION

The Normalized Difference Vegetation Index (NDVI),

$$ND\ VI = \frac{L_{IR}^{surf} - L_{R}^{surf}}{L_{IR}^{surf} - L_{R}^{surf}} \tag{1}$$

is a good indicator of vegetation cover, Here, L_{IR}^{surf} and L_{R}^{surf} are the surface-leaving radiances in the near-infiarcd and red spectral bands, respectively, chosen because of the strong chlorophyll aborpion shortwards of 0.7 pm. Thus, for dense vegetation L_{R}^{surf} generally will be much smaller than L_{IR}^{surf} and the NDVI will be close to unity. In addition to its usc as an indicator of vegetation, the NDVI is also sensitive to variations in atmospheric CO_2 concentration [1], rainfall amount in semi-arid regions [2], and amount of canopy photosynthesis [3]. Clearly, global monitoring of NDVI, using satellite radiance measurements, plays an important role in the remote sensing of the biosphere. Because this particular vegetation index is formed as a radiance ratio, it is relatively insensitive to radiometric calibration errors, but satellite radiance measurements in the red and near-infrared also are contaminated by atmospheric effects, particularly aerosol scattering. For satellite observations of a vegetated area the red band radiance at the top of the atmosphere (TOA) will be larger than its surface-leaving counterpart, due to additional components of multiple scattered radiation occurring within the atmosphere. The countcracting effect of a decrease in the surface-leaving radiance component due to attenuation is relatively small, In the near-infrared, however, the TOA radiance is generally similar in value to its surface-leaving counterpart because the additional multiple scattered radiation component is more closely balanced in value by the attenuated surface-leaving radiance component. Thus, the NDVI, computed using the TOA radiances can be considerably smaller for a densely vegetated area than the corresponding NDVI computed using the surface-leaving radiances. Since the atmospheric properties are not generally known, correction of the measurements from currently flying satellites for atmospheric effects is, at best, imprecise. There have been attempts to create new vegetation indices which are more atmosphere insensitive [4, 5], but so far they are still in a state of limited acceptance and usage.

It is shown in this study that the NDVI, as defined in (1) for red and near-infrared surface-leaving radiances, can also be derived from TOA red and near-infrared radiances, assuming no prior knowledge of atmospheric propcrties, if the TOA observations are made at a number of different view zenith angles. 1 'reserving this standard definition for vegetation index, in contrast to the newer, atmosphere-insensitive vegetation indices mentioned above, allows some historical continuity to be achieved.

THEORY

The TOA radiance L_λ at wavelength λ can be written as

$$L_\lambda(-\mu, \mu_0, \phi - \phi_0) = L_\lambda^{atm}(-\mu, \mu_0, \phi - \phi_0)$$
$$+ \exp(-\tau_\lambda/\mu) \cdot L_\lambda^{surf}(-\mu, \mu_0, \phi - \phi_0) \tag{2}$$
$$+ \int_0^{2\pi}\int_0^1 T_\lambda(-\mu, -\mu', \phi - \phi') L_\lambda^{surf}(-\mu', \mu_0, \phi' - \phi_0) d\mu' d\phi'$$

where μ and μ_0 arc the cosines of the view and Sun zenith angles and $\phi - \phi_0$ is the view azimuthal angle with respect to the Sun position. The convention $-\mu$ and μ is used for upwelling and downwelling radiation, respectively. On the right-hand-side of (2) L_λ^{atm} is the radiance field scattered by the atmosphere to space without interacting with the surface (i.e., the path radiance), τ_λ is the optical depth of the atmosphere, L_λ^{surf} is the surface-leaving radiance, and T_λ is

the upward diffuse transmittance. Equation(2) describes the relationship between the TOA radiance L_λ and the surface-leaving radiance L_λ^{surf}.

In a mathematically formal sense, it can be shown (e.g., through the method of successive orders of scattering) that,

$$\lim_{1/\mu \to 0} L_\lambda^{atm} \to O \tag{3}$$

$$\lim_{1/\mu \to 0} T_\lambda \to O \tag{4}$$

and, therefore,

$$\lim_{1/\mu \to 0} L_\lambda \to \lim_{1/\mu \to 0} L_\lambda^{surf}. \tag{5}$$

Using (5), we then can re-express (1) as

$$\lim_{1/\mu \to 0} NDVI = \lim_{1/\mu \to o} \frac{L_{IR}^{surf} - L_R^{surf}}{L_{IR}^{surf} + L_R^{surf}}$$

$$= \lim_{1/\mu \to 0} \frac{L_{IR} - L_R}{L_{IR} + L_R} \tag{6}$$

where the surface-leaving radiances are replaced by TOA radiances,

Since μ is physically restricted to values less than or equal to unity ($\mu = 1$ implies a nadir view), there can be no physical measurement of $NDVI$ (or L_λ) corresponding to $1/\mu=0$. It is, however, possible (and practical) to extrapolate the measured $NDVI$ to its hyper-value at $1/\mu=0$. Expression (6) implies that the $NDVI$ derived from TOA radiances have the same hyper-value as those derived from surface-leaving radiances. Thus, the hyper-value of $NDVI$ (i .e., $NDVI$ at $1/\mu= 0$), obtained from TOA radiances, is basically independent of the atmospheric condition including aerosol properties.

EXAMPLES

Example 1: We first consider a lambertian surface with a reflectance of 0.03 in the red band and 0.7 in the near-infrared band. This results in a $NDVI = 0.918$ which is independent of view angle, Thus, the hyper-value of NDW is also 0.918. The TOA radiances associated with this lambertian surface were computed using a multiple scattering, discrete ordinate, radiative transfer code [6] and included both Rayleigh and aerosol scattering. The computations were performed assuming red and near-infrared wavelengths of 0,670 and 0.865 μm, respectively, and nine viewing zenith angles (0°, ±26, 10, ±45.6°, ±60.0°, and ± 70.50), symmetrically placed about the nadir in a single nadir-azimuth angle plane. These spectral bands and viewing geometry are instrument characteristics of the Multi-angle Imaging SpectroRadiometer (MISR) to be flown on the EOS-AM 1 platform. The aerosol

was specified to be a waler soluble type with phase function asymmetry parameters $g_R = 0.628$ and $g_{IR} = 0.609$ and single scattering albedos $\omega_R = \omega_{IR} = 1,0$. Three aerosol amounts were considered, specified by optical depths τ_R^{aer} of 0.1, 0.25, and 0.5. The solar zenith angle and the azimuth angle difference between the Sun position and the forward-looking views were set at 45° and 330°, respectively. Fig. 1 shows the resulting angle-dependent $NDVI$, computed using (6) with the TOA radiance, plotted as a function of $1/\mu$ for the three aerosol amounts, Also shown are the $NDVI$, computed using (6) with the surface-leaving radiances, and the hyper-value NDW at 0.918. Linear regression anal *yscs* of the three aerosol datasets to obtain the hyper-value $NDVI$ (the y-axis intercept) would produce good estimates of the true hyper-value.

Example 2: The next surface type is a pine forest canopy, using actual field measurements [7] to define the surface directions I reflectance properties. The directional reflectance has the characteristic bowl-shape appearance for forest canopies (weakly reflecting in the nadir view and increasing reflectance with increasing off-nadir viewing). This bowl-shape also is more. pronounce.d in the red than in the infra-red band. The same Sun and viewing geometries and atmospheric conditions as for the previous example were also used here. Fig, 2 is similar to Fig. 1, showing the angular variation of the $NDVI$ of the TOA radiances for the three aerosol amounts and the $NDVI$ of the surface-leaving radiances. The hyper-value $NDVI$ is about 0.83, based on the $NDVI$ of the surface-leaving radiances, A good estimate of the hyper-value from the $NDVI$ based on the TOA radiances again could be accomplished with a linear regression analysis.
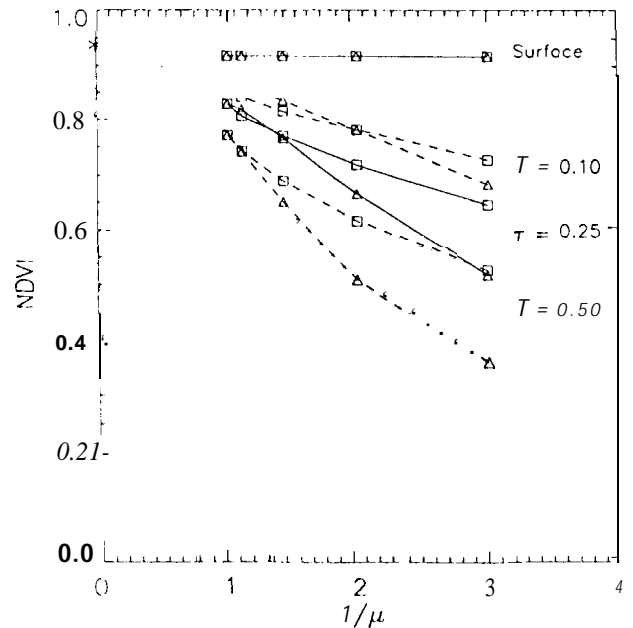

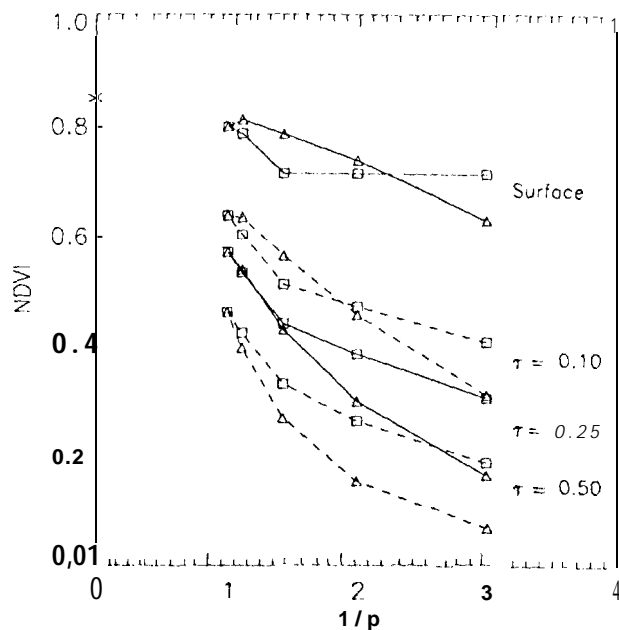Fig. 1. View angle variation of NDVI for a lambertian vegetation cover.

Fig. 2. View angle variation of NDVI for a pine forest canopy.

SUMMARY

The view angle variation of *NDVI*, as derived from TOA radiances, can provide a means for estimating the *NDW* at the surface (i .e., an atmospheric corrected index). No atmospheric properties need to be known and radiative transfer modelling is not required. Results using simulated data suggest that a simple regression analysis of the angle-dependent TOA *NDVI* is sufficient to retrieve a measure of the surface *NDVI (the hyper-value).*

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